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# New CDF Results on Diffraction

Christina Mesropian

*The Rockefeller University*

# Outline

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## *Introduction*

## *Diffractive Structure Function*

*Ratio of SD/ND dijets vs  $x_{bjorken}$*

*$Q^2$  dependence of SD/ND ratio*

*$Q^2$  dependence of  $t$  in SD dijets*

## *Exclusive Production*

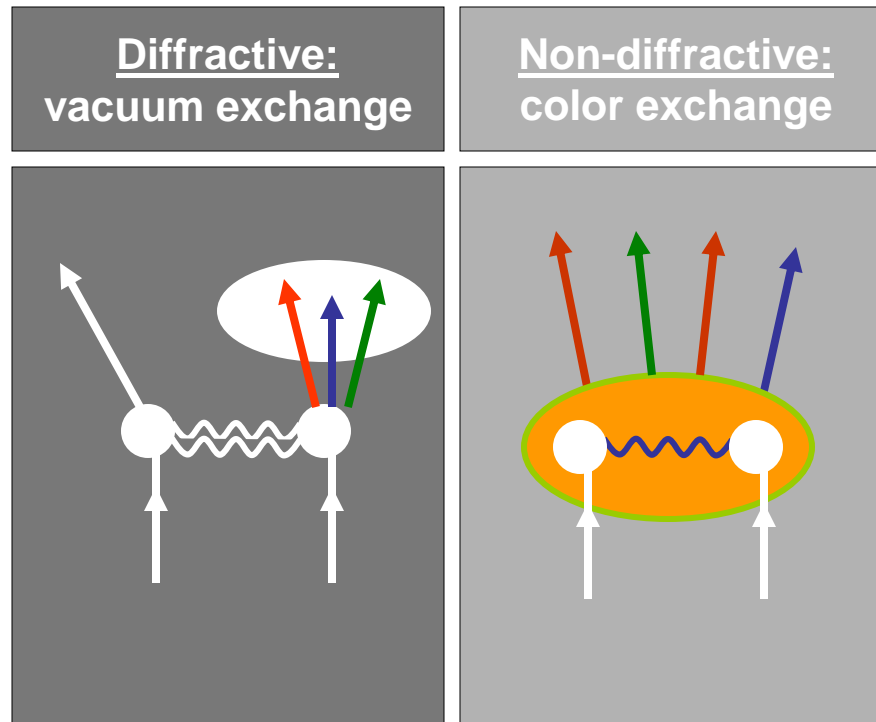
*Exclusive dijets*

*Inclusive + Exclusive dijet Monte Carlo*

*Heavy flavor jet fraction*

*Exclusive  $e^+e^-$  and  $\gamma\gamma$  production*

# *Diffraction at the Tevatron*

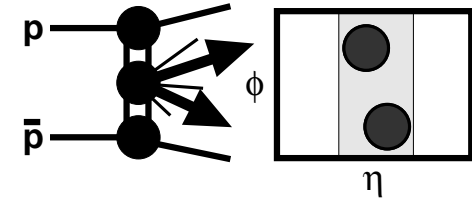
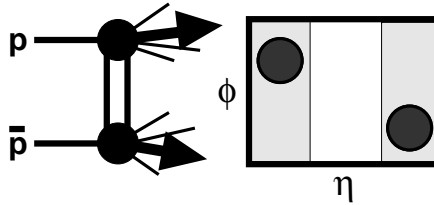
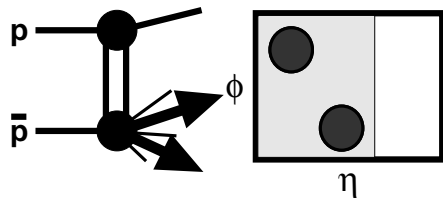


## **Goals of Diffractive Program at CDF:**

To understand the nature of colorless exchange

To test the feasibility of diffraction as a tool to search for new physics at the LHC

# *Diffraction at CDF in Run I*



## Soft Diffraction

### Single Diffraction

PRD 50, 5355 (1994)

### Double Diffraction

PRL 87, 141802 (2001)

### Double Pomeron Exc.

PRL 93, 141601 (2004)

### Multi-Gap Diffraction

PRL 91, 011802 (2003)

## Hard Diffraction

### Rapidity Gap Tag

**W** PRL 78, 2698 (1997)

**Dijets** PRL 79, 2636 (1997)

**b-quark** PRL 84, 232 (2000)

**J/Ψ** PRL 87, 241802 (2001)

### Roman Pot Tag

#### Dijets:

**1.8 TeV** PRL 84, 5043 (2000)

**630 GeV** PRL 88, 151802 (2002)

### Jet-Gap-Jet

**1.8 TeV** PRL 74, 855 (1995)

**1.8 TeV** PRL 80, 1156(1998)

**630 GeV** PRL 81, 5278(1998)

### Dijets:

**1.8 TeV** PRL 85, 4217 (2000)

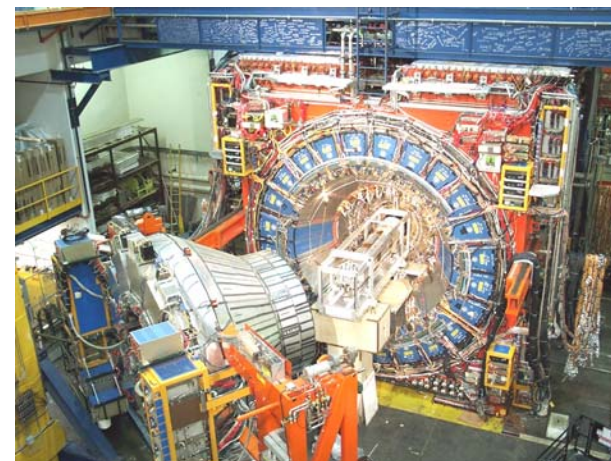
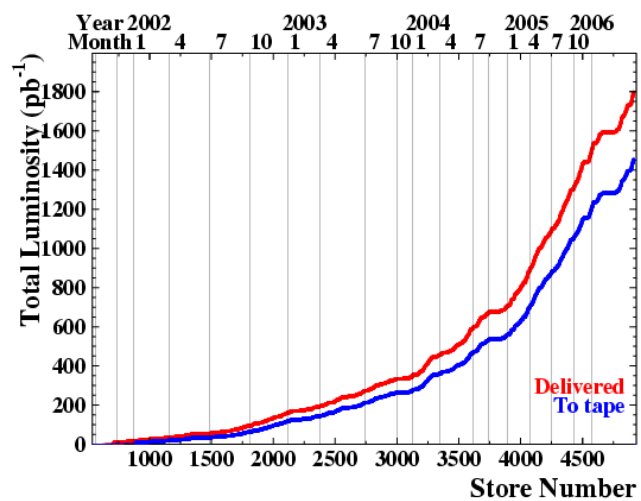
# Run II



**Tevatron:**

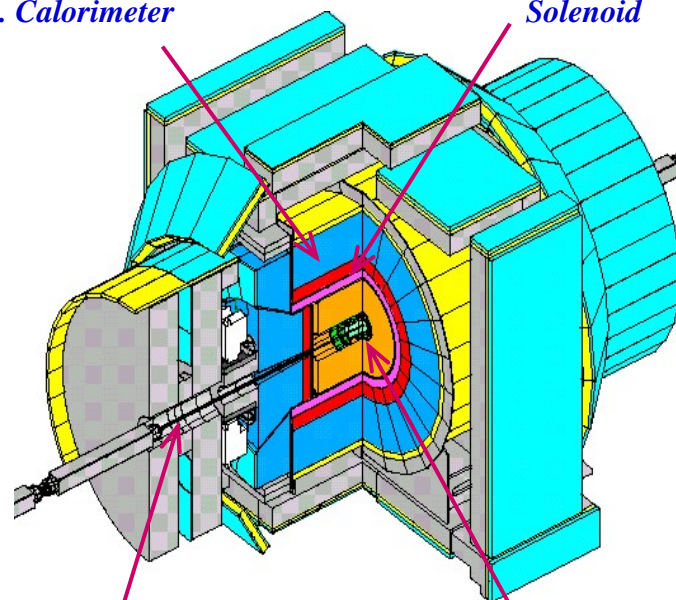
$\sqrt{s} = 1.96 \text{ TeV}$

396 nsec bunch spacing 36x36



*Cent. Calorimeter*

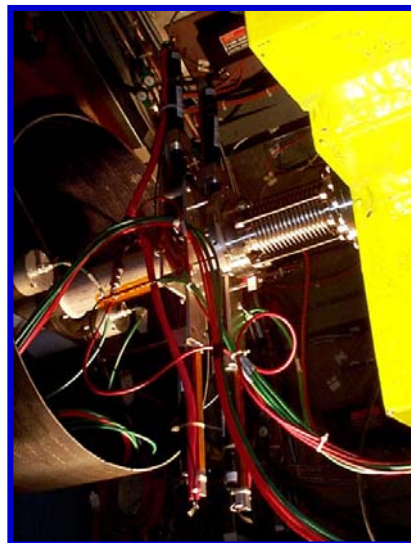
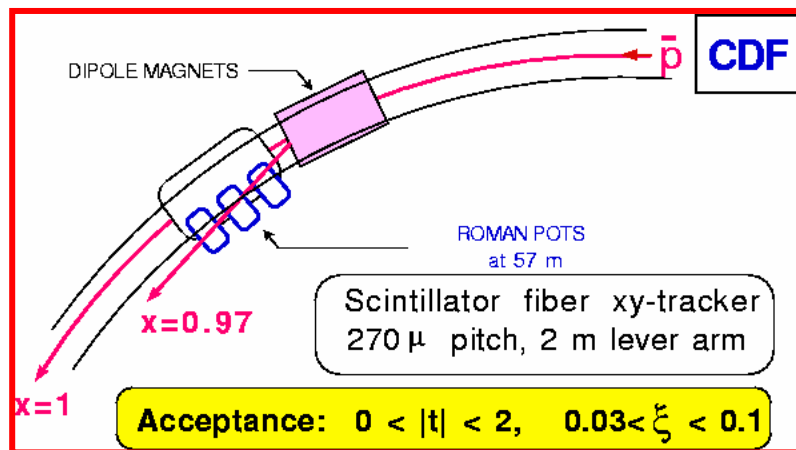
*Solenoid*



*MiniPlug  
Calorimeter*

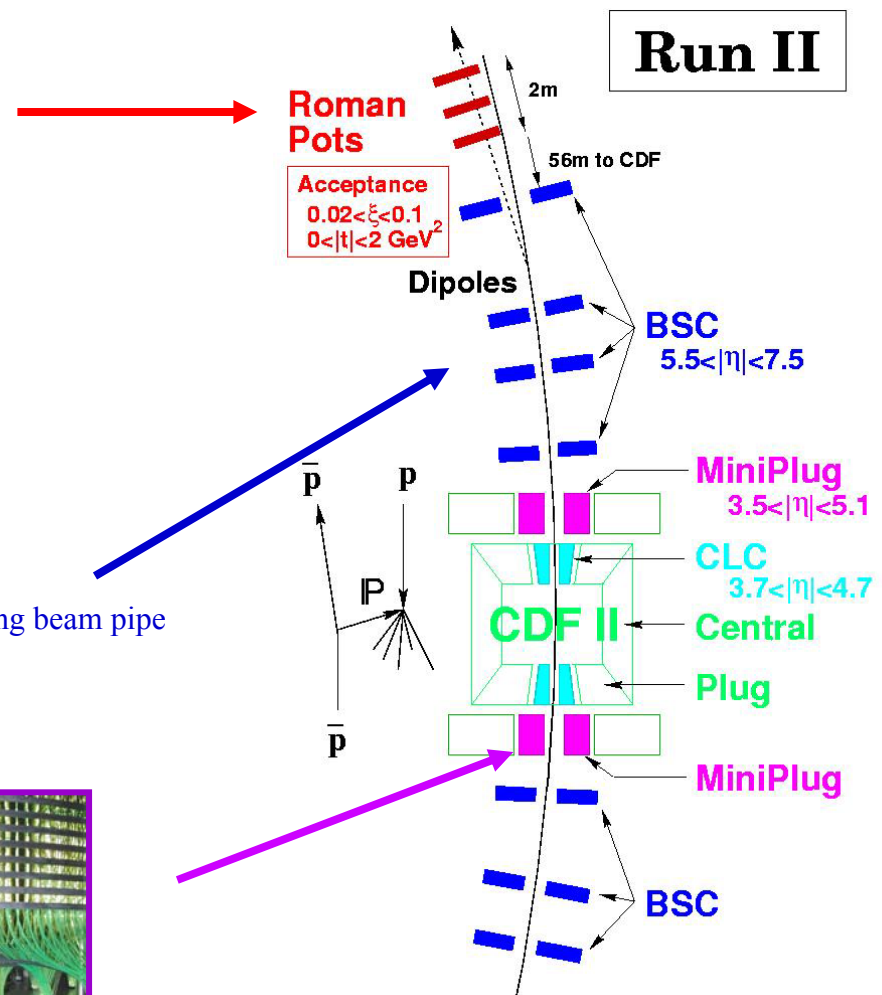
*Central  
Tracker*

# Run II: Forward Detectors

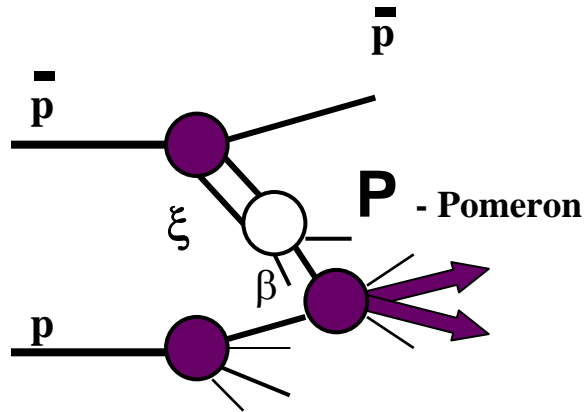


## Scintillation counters:

detect particles traveling from IP along beam pipe  
 $5.5 < |\eta| < 7.5$  coverage



# The Diffractive Structure Function



parton  $x = \beta\xi$

$\beta$  – fraction of **P** momentum  
carried by parton

$\xi$  – fractional momentum loss of  $\bar{p}$

**Hard diffraction:**

production of high  $p_T$  dijets

Diffractive dijets

$$\sigma(\bar{p}p \rightarrow \bar{p}X) \approx F_{jj} \otimes F_{jj}^D \otimes \hat{\sigma}(ab \rightarrow jj)$$

Study the **diffractive structure function**

$$F_{jj}^D = F_{jj}^D(x, Q^2, t, \xi)$$

Experimental Determination of  $F_{jj}^D$

$$R_{\frac{SD}{ND}}(x, \xi) = \frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F_{jj}^D(x, Q^2, \xi)}{F_{jj}(x, Q^2)} \text{ (LO QCD)}$$

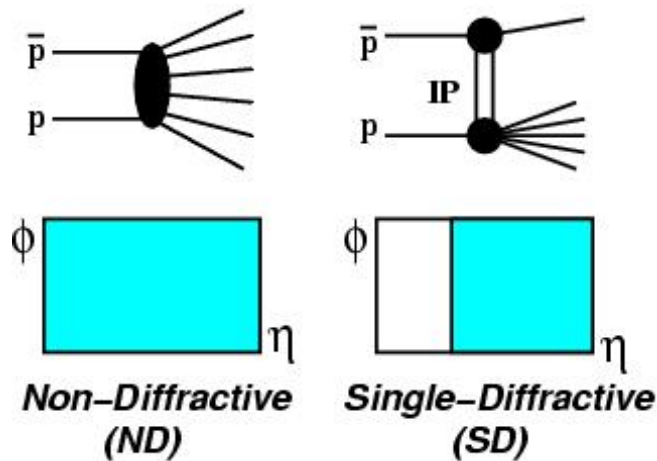
Data

known PDF

# Run II: Diffractive Dijets



## Process



## Data:

ND :  
J5 trigger

$\geq 1$  cal. tower  
with  $E_T > 5$  GeV

SD :  
RP+J5 trigger

leading  $\bar{p}$  +  
 $\geq 1$  cal. tower  
with  $E_T > 5$  GeV

## Method

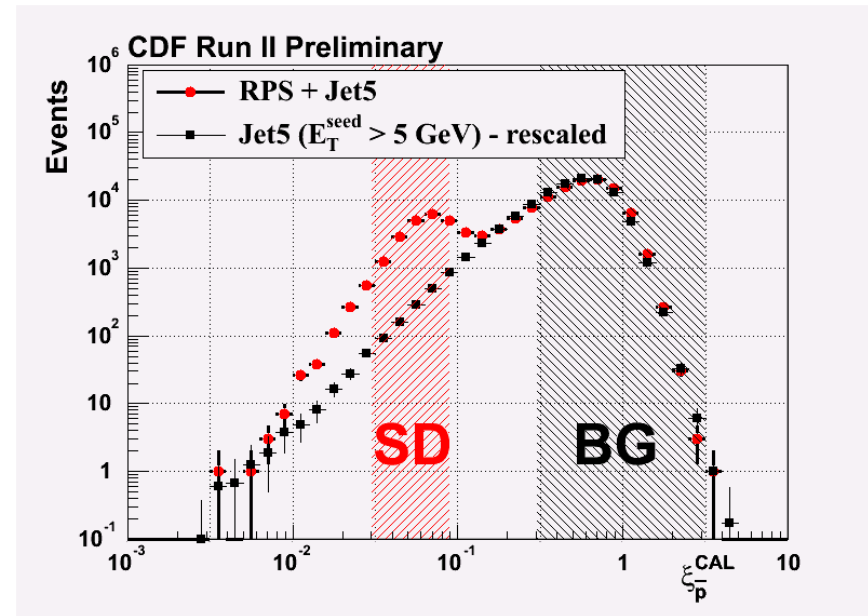
measure  $\xi$  from calorimeter information

sum all towers except  $\bar{p}$

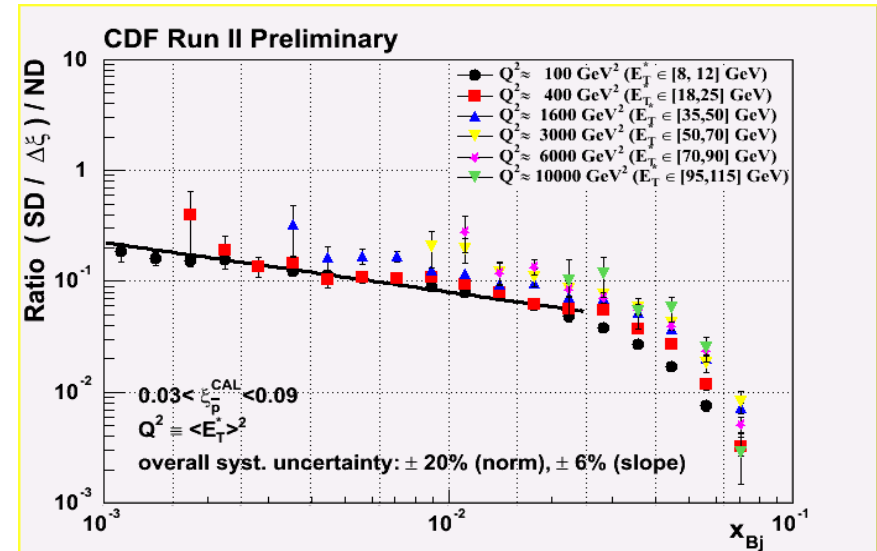
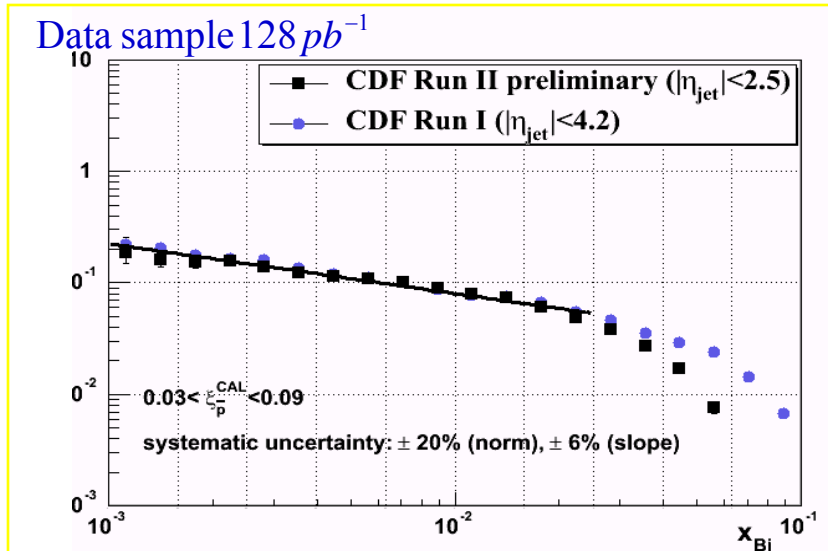
$$\xi_{\bar{p}}^X = \frac{M_X^2}{s} \approx \frac{1}{\sqrt{s}} \sum_i E_T^i e^{-\eta^i}$$

MP energy scale:  $\pm 25\% \rightarrow \Delta \log \xi = \pm 0.1$

RP acceptance ( $0.03 < \xi < 0.1$ )  $\sim 80\%$  (Run I)



# Diffractive Structure Function



Ratio of SD to ND dijet event rates  
as a function of  $x_{BJ}$  compared with Run I

No  $\xi$  dependence is observed within  
 $0.03 < \xi < 0.1$

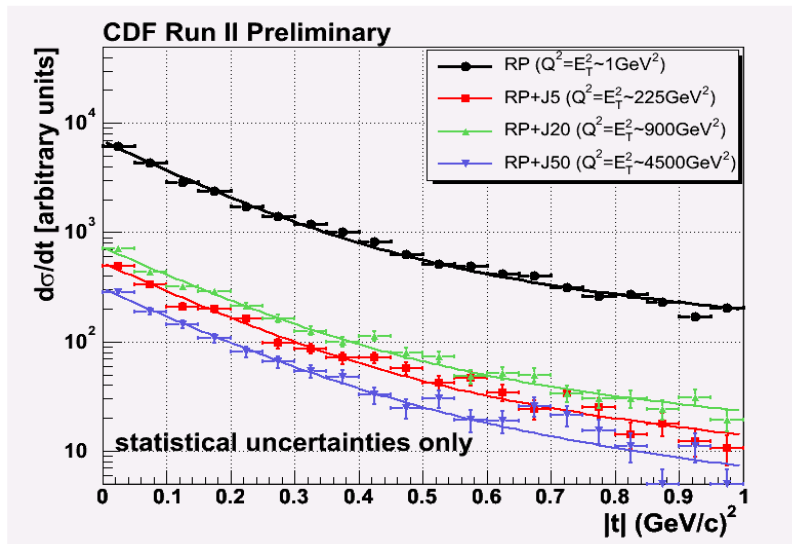
**Confirms Run I result**

Ratio of SD to ND dijet event rates  
as a function of  $x_{BJ}$  for different  
values of  $Q^2 \equiv E_T^2$

**No significant dependence is  
observed for  $100 < Q^2 < 10000\text{ GeV}^2$**

Pomeron evolves like proton?

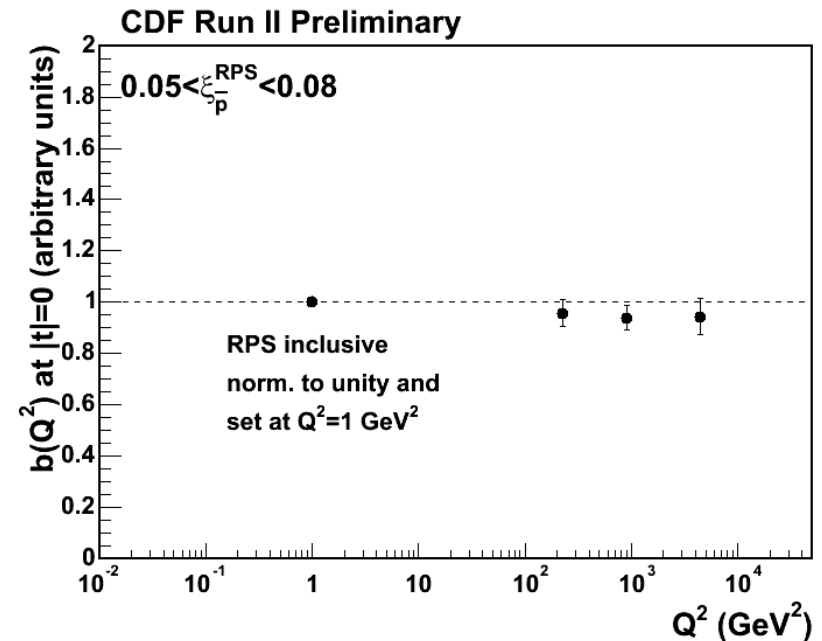
# Diffractive Structure Function:



Fit  $\frac{d\sigma}{dt}$  to a double exponential

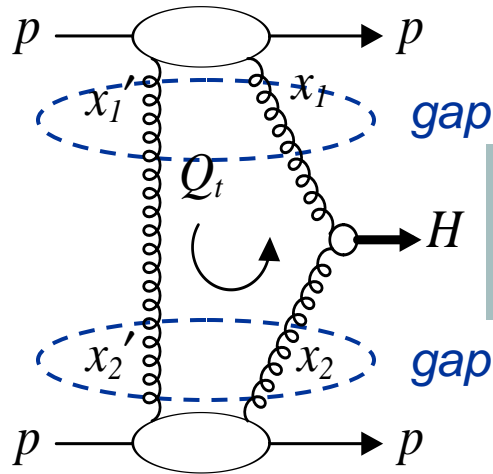
$$F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t}$$

no diffraction dips  
no  $Q^2$  dependence in slope  
from inclusive to  $Q^2 \sim 10^4 \text{ GeV}^2$



same slope at  $t=0$  for  
entire region of  
 $0 < Q^2 < 4500 \text{ GeV}^2$

# Diffraction Higgs Production in DPE



Bialas and Landshoff  
Khoze, Martin, Ryskin  
Boonekamp, Peschanski, Royon

## Attractive channel for Higgs discovery at LHC

Standard Model light Higgs:

$$p + p \rightarrow p + H (\rightarrow b\bar{b}) + p$$

“exclusive channel”  $\rightarrow$  clean signal

$$M_H = M_{miss} = (s \cdot \xi_p \cdot \xi_{\bar{p}})^{1/2}$$

$$\sigma_H^{excl} \sim 3 \text{ fb},$$

signal/background  $\sim 3$  @ LHC (if  $\Delta M_{miss} = 1 \text{ GeV}$ )

To calibrate Diffractive Higgs predictions

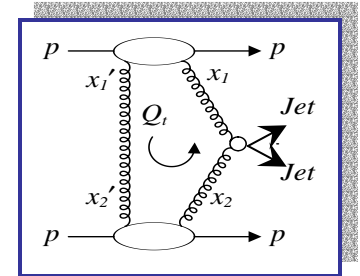


exclusive production in DPE

Exclusive **Dijets**:

$$gg^{PP} \rightarrow gg$$

large cross section

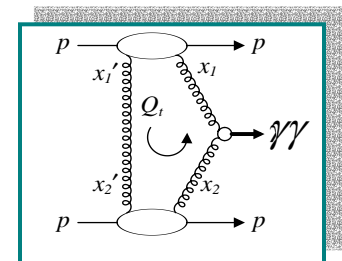


exclusive  $gg^{PP} \rightarrow q\bar{q}$  suppressed

Exclusive  $\gamma\gamma$ :  $gg^{PP} \rightarrow \gamma\gamma$

small cross section

clean signal



# Search for Exclusive Dijets

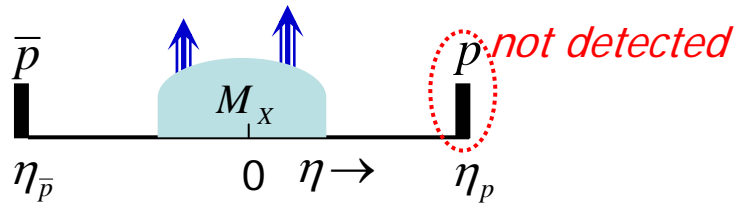


## Method:

Select diffractive dijet events  
produced by DPE

$$p + \bar{p} \rightarrow \bar{p} + X (\geq 2 \text{ jets}, \dots) + \text{gap}$$

Data sample of  $428 \text{ pb}^{-1}$



## Reconstruct

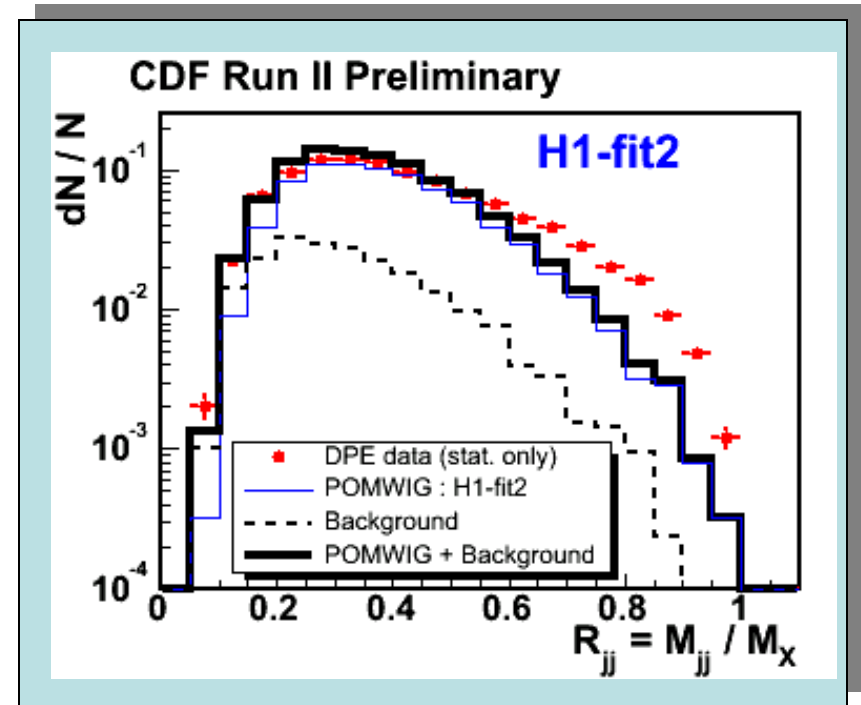
$$R_{jj} = \frac{M_{jj}}{M_X}, \text{ where}$$

$$M_{jj} = \sqrt{(E_{jet1} + E_{jet2})^2 - (\vec{P}_{jet1} + \vec{P}_{jet2})^2}$$

is a dijet mass  
and  $M_X$  is the mass of the system  $X$

## Compare

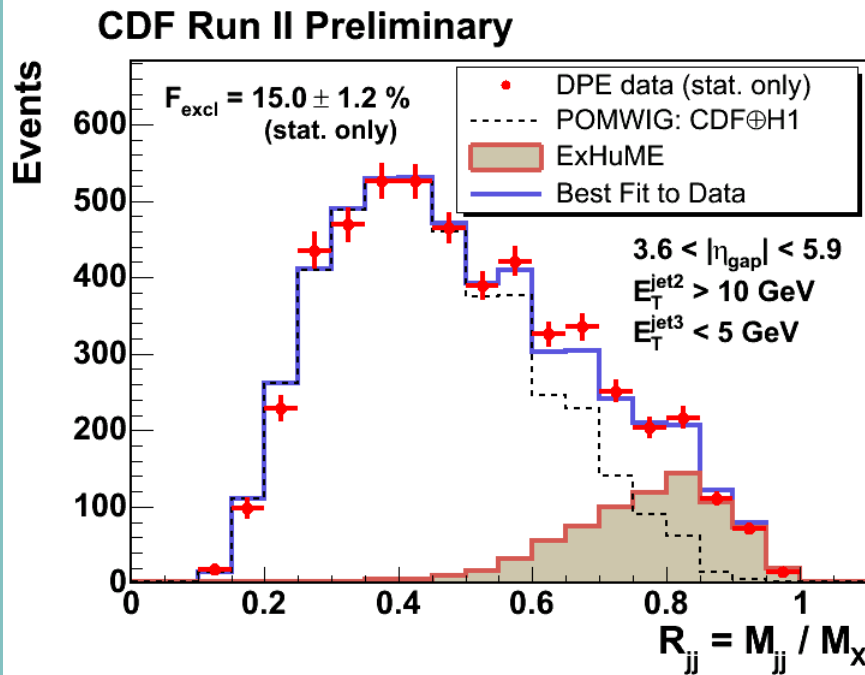
with inclusive DPE Monte Carlo POMWIG



Excess of events in data  
observed at high  $R_{jj}$

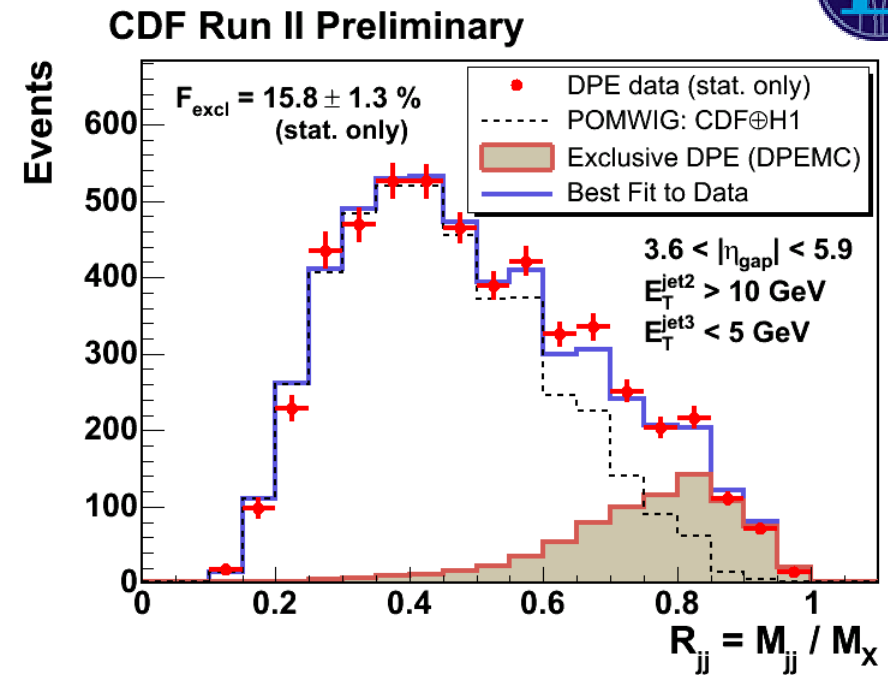
Is this an exclusive signal?

# Inclusive+Exclusive Dijet: MC vs Data



ExHuME :  $gg \rightarrow gg$

LO matrix element event generator based on pQCD calculations of KMR



Exclusive DPE (in DPEMC) :

$PP \rightarrow 2 \text{ jets}$

Regge inspired non-perturbative production of excl. events based on BL

The excess at high  $R_{\text{jj}}$  is well described by the two exclusive dijet production models

# Heavy Flavor Jet Fraction vs $R_{jj}$



## Theory

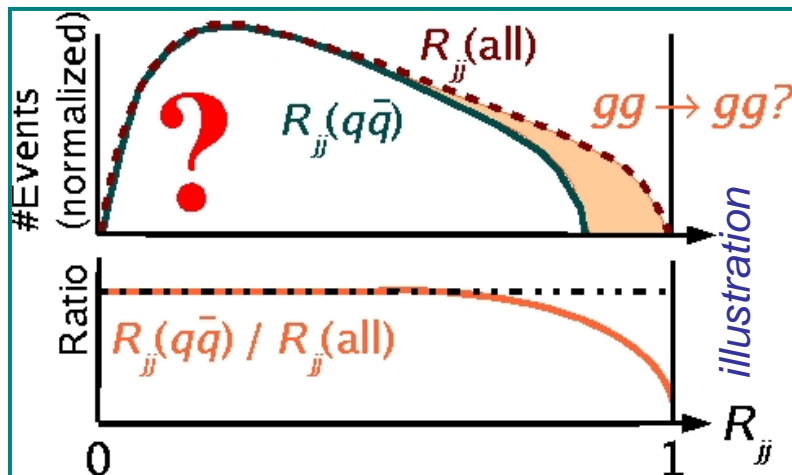
$gg \rightarrow gg$  contribution is dominant in LO

$gg \rightarrow q\bar{q}$  is suppressed when  $M_{jj} \gg m_q$

## Experimental Method - using $b/c$ -Quark Jets

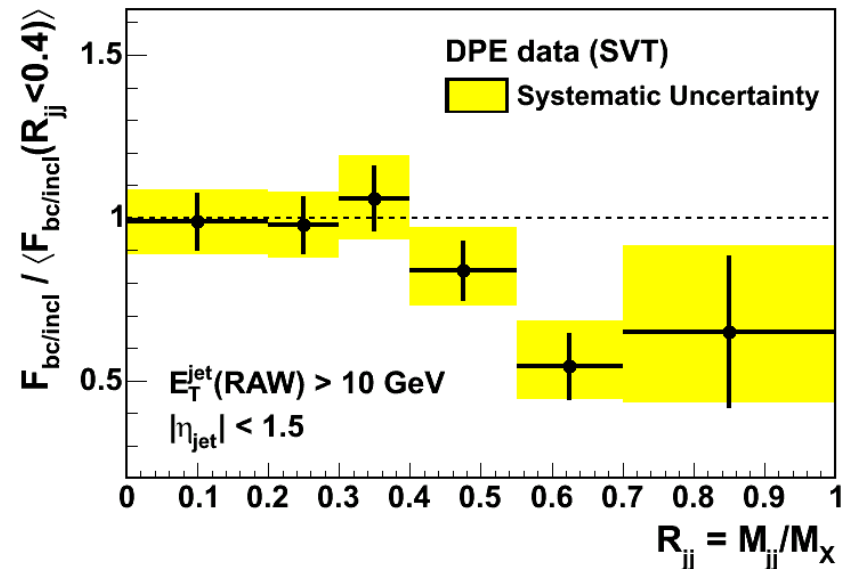
look for the suppression of  $b$ -quark jet fraction in the exclusive region

*many exp. systematics canceled out*  
*HF quarks identifies well*



## Results:

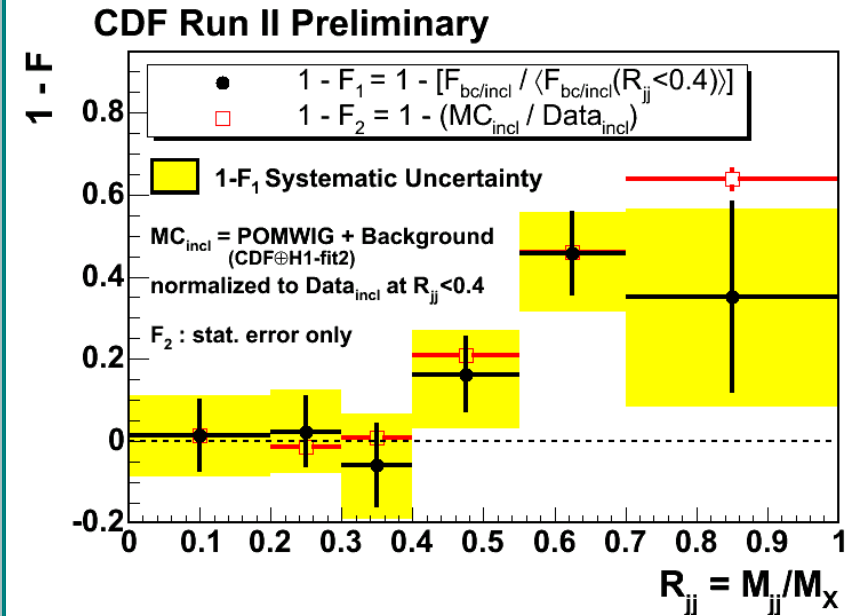
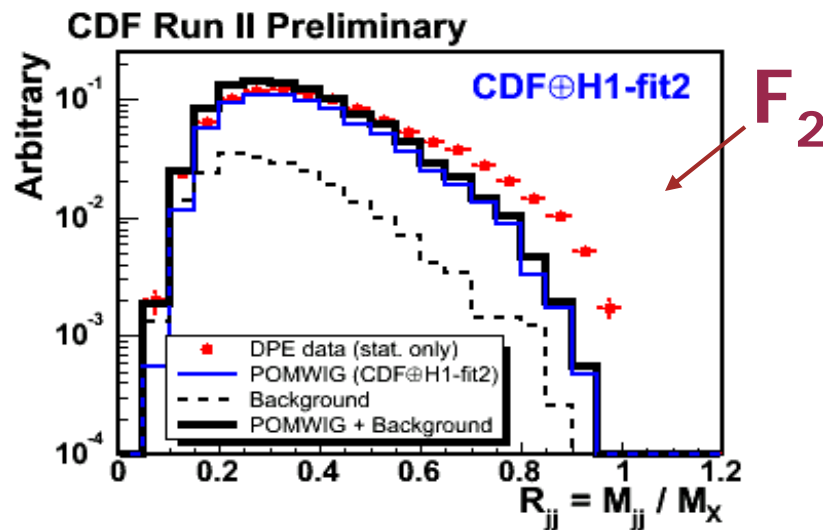
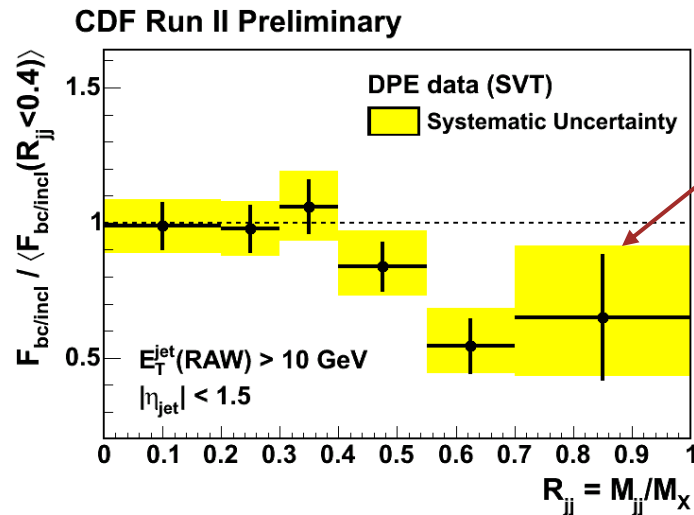
### CDF Run II Preliminary



Ratio of  $b/c$ -jets to all jets  
(normalized to the mean in  $R_{jj} < 0.4$ )

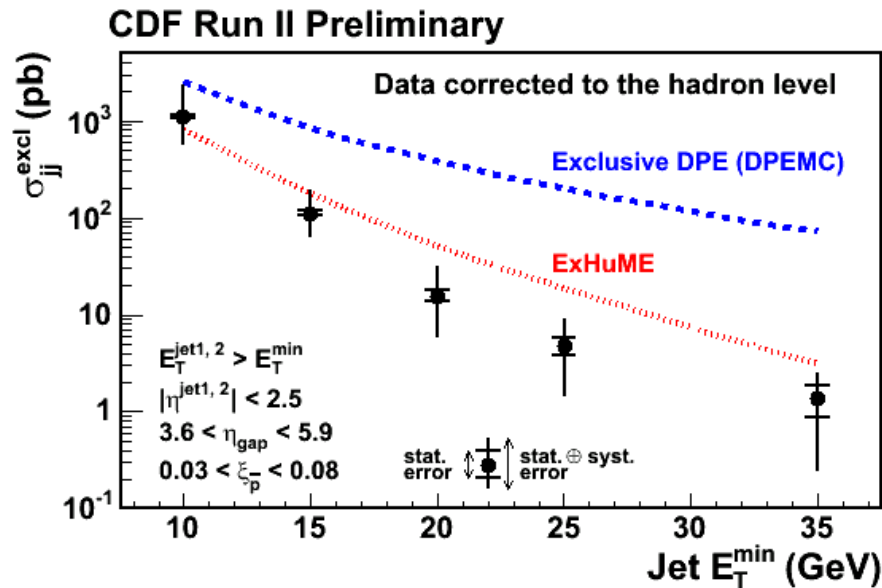
**Decreasing trend observed  
at high  $R_{jj}$**

# Comparing Inclusive Jet and Heavy Flavor Jet Results

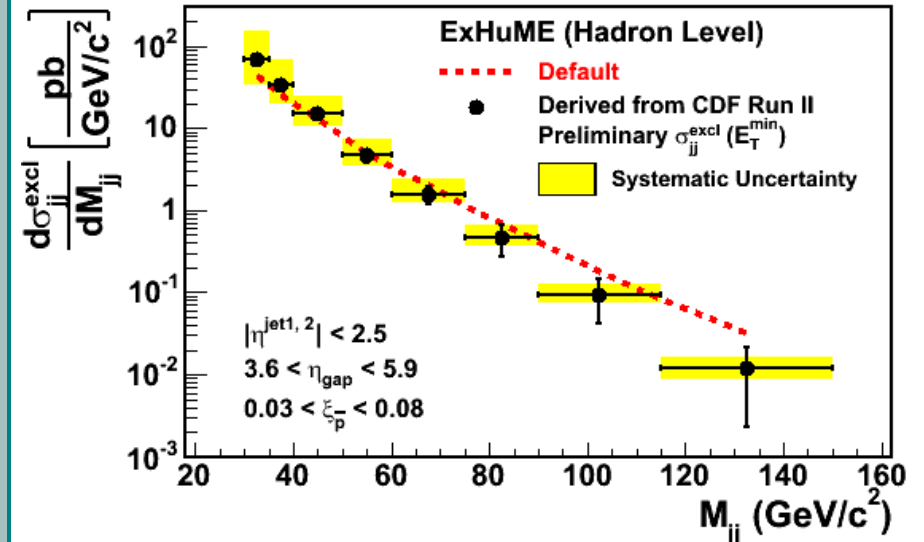


The two results are consistent with each other

# Exclusive Dijet Cross Section

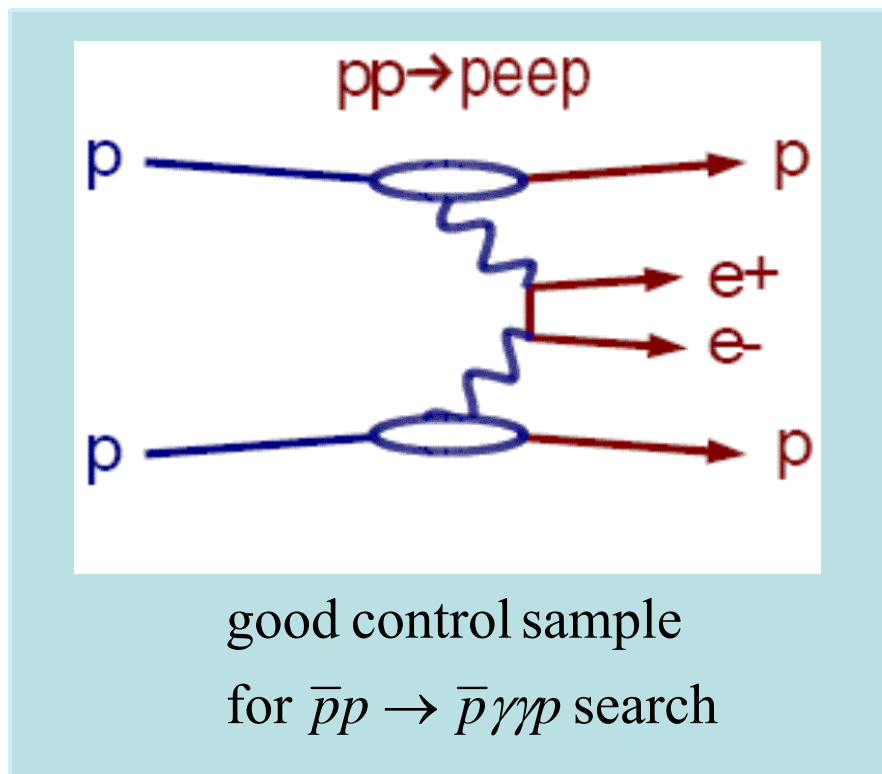


$E_T$  dependence of the exclusive dijet cross section strongly prefers ExHuME MC based on KMR



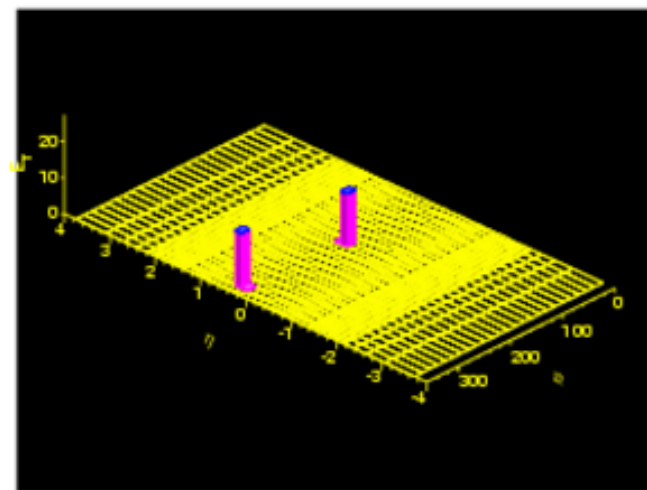
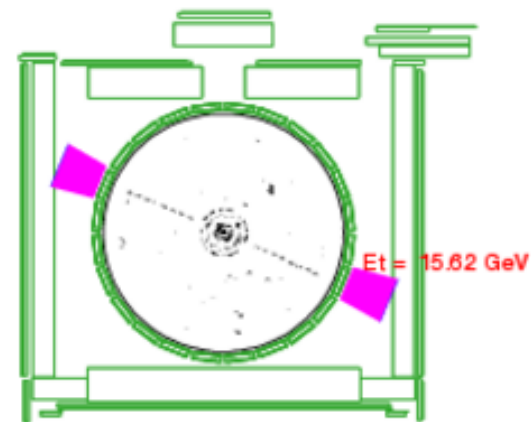
ExHuME MC agrees with cross section as function of the dijet mass,  $M_{jj}$

# Exclusive $e^+e^-$ Production



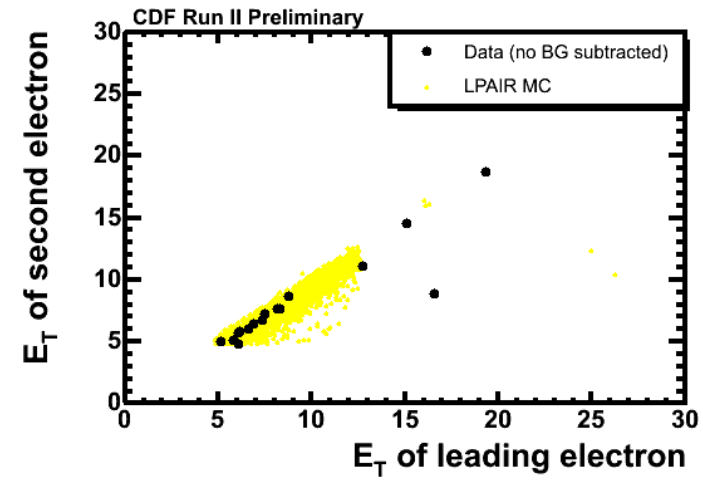
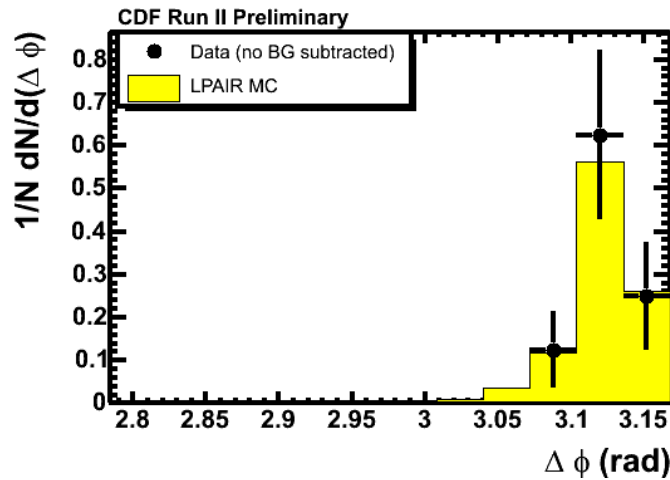
## Select $e^+e^-$ events:

reconstruct  $e^+e^-$   
request no additional calorimeter activity  
protons are not tagged



16 similar events are found

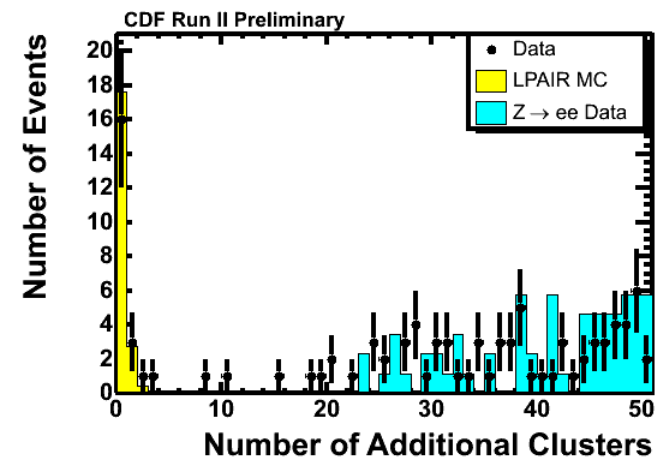
# Exclusive $e^+e^-$ Production



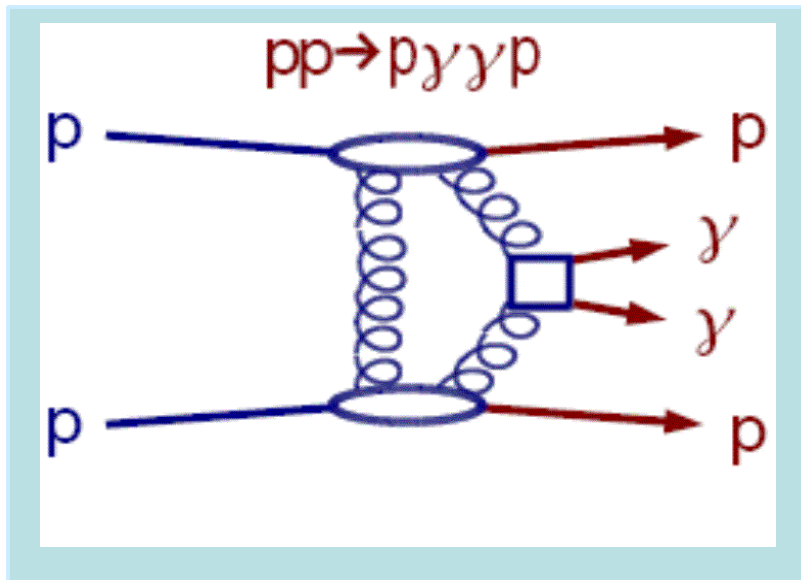
Background estimate  $2.1^{+0.7}_{-0.3}$

$$\sigma_{\text{exp}} = 1.6^{+0.5}_{-0.3}(\text{stat}) \pm 0.3(\text{sys}) \text{ pb}$$

$$\sigma_{\text{LPAIR}} = 1.711 \pm 0.008 \text{ pb}$$

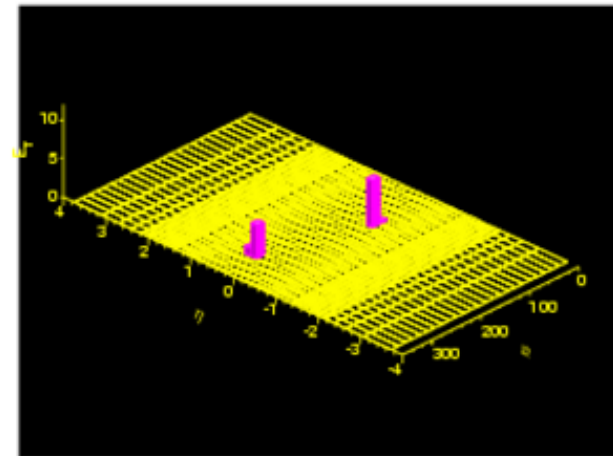
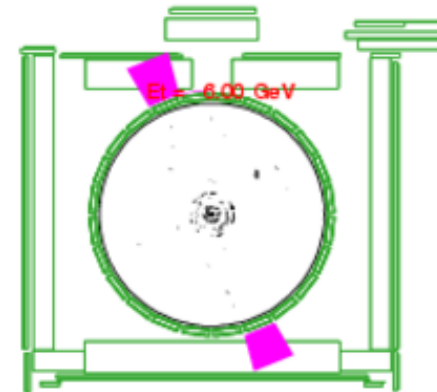


# Exclusive $\gamma\gamma$ Production



## Exclusive $gg$ events:

select in the same way as  $e^+e^-$ ,  
(except for tracking)  
agreement of exclusive  $e^+e^-$  cross section  
provides cross check of the methodology



3 events are found

$1_{-1}^{+3}$  events are predicted from ExHuME MC

Background estimate is not yet complete

# Summary

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## New CDF results on Diffraction

### Diffraction Structure function

Extended Run I results using single diffractive dijets  
no  $Q^2$  dependence  
slope at  $t=0$  is independent of  $Q^2$

### Exclusive Production

**observed excess events at high  $R_{jj}$  being consistent  
with exclusive dijets**

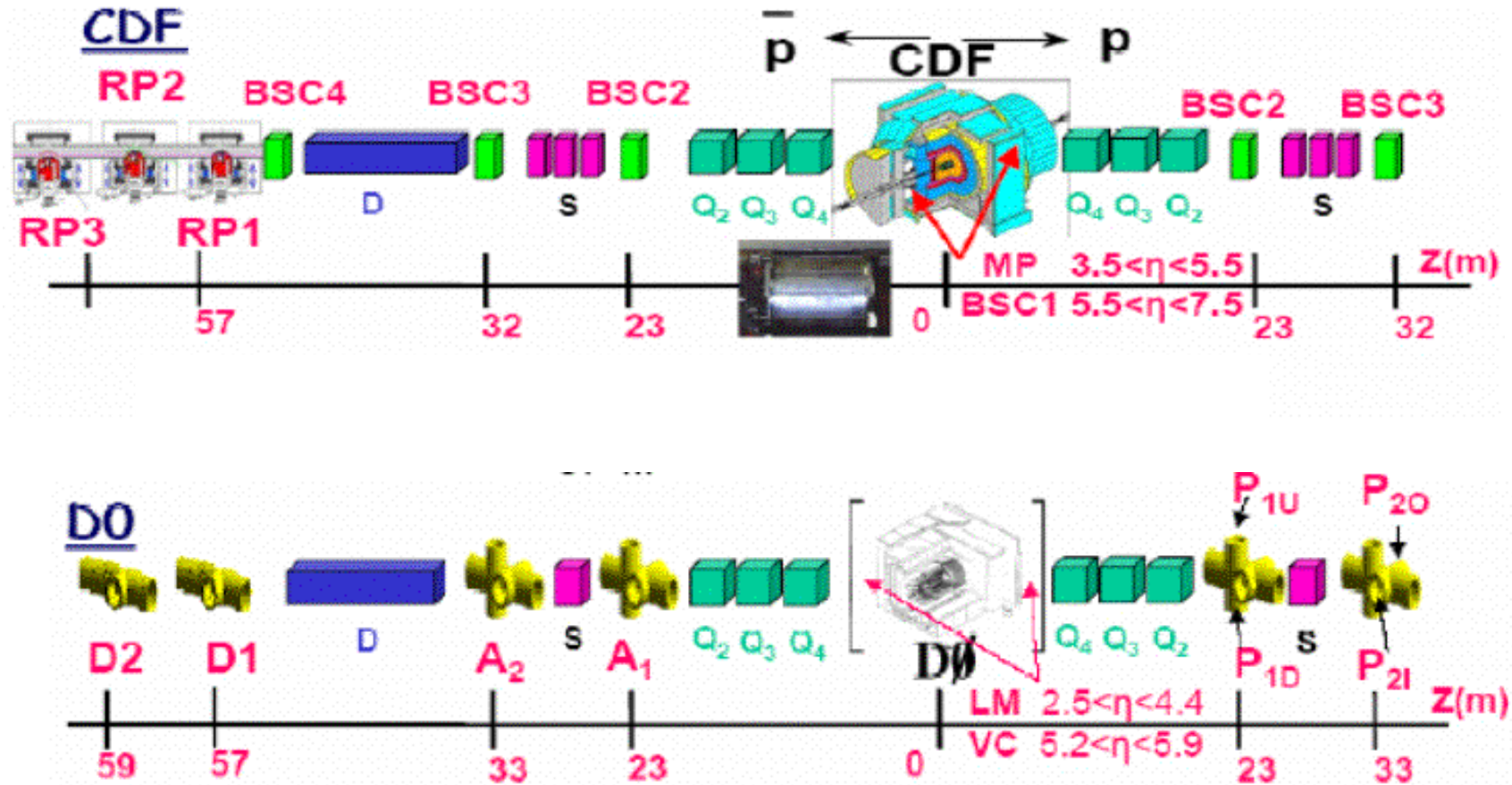
observed events being consistent with exclusive gg production

exclusive  $e^+e^-$  production – cross check for di-photons

# *Backup slides*

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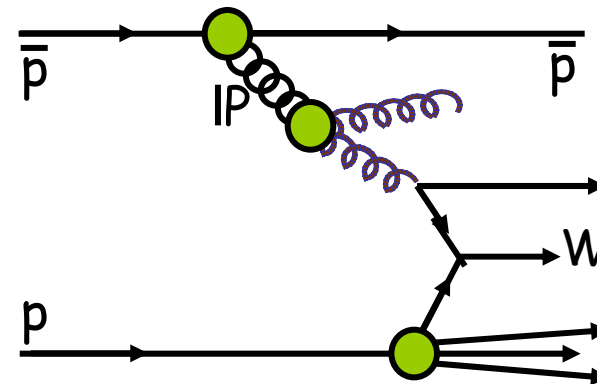
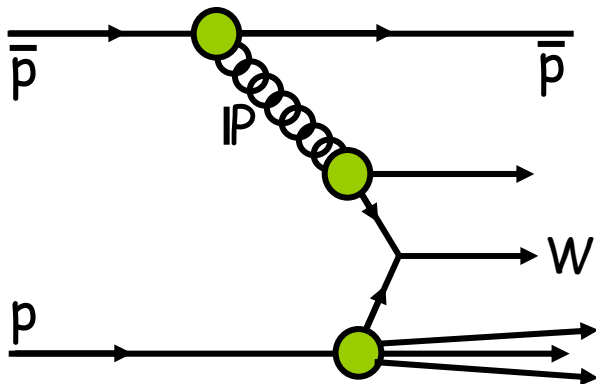
# Run II Detectors



# *Diffractive W (Z) Production*

Study diffractive W-boson production, and the partonic structure of the Pomeron by a comparison to the diffractive dijet production

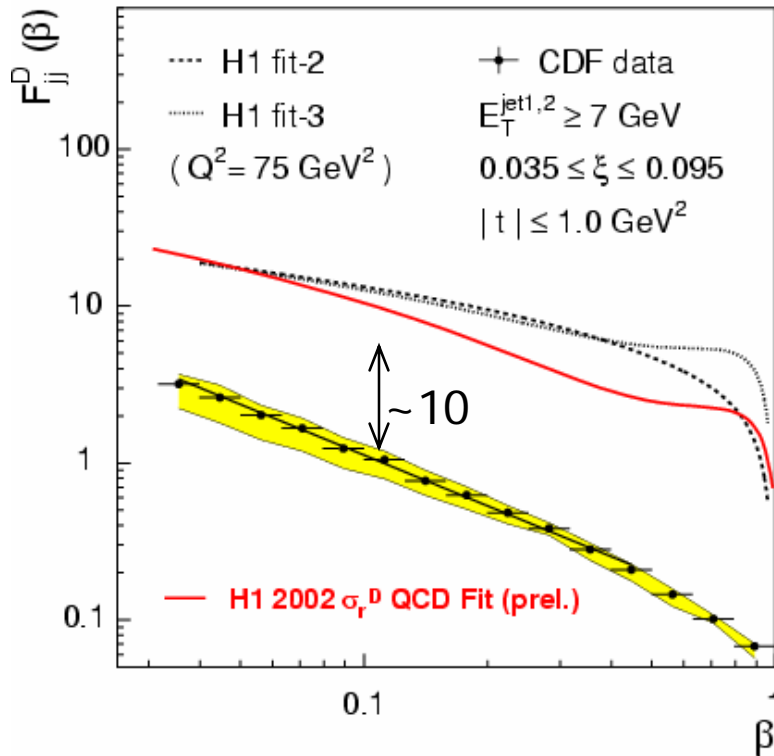
Analysis in progress



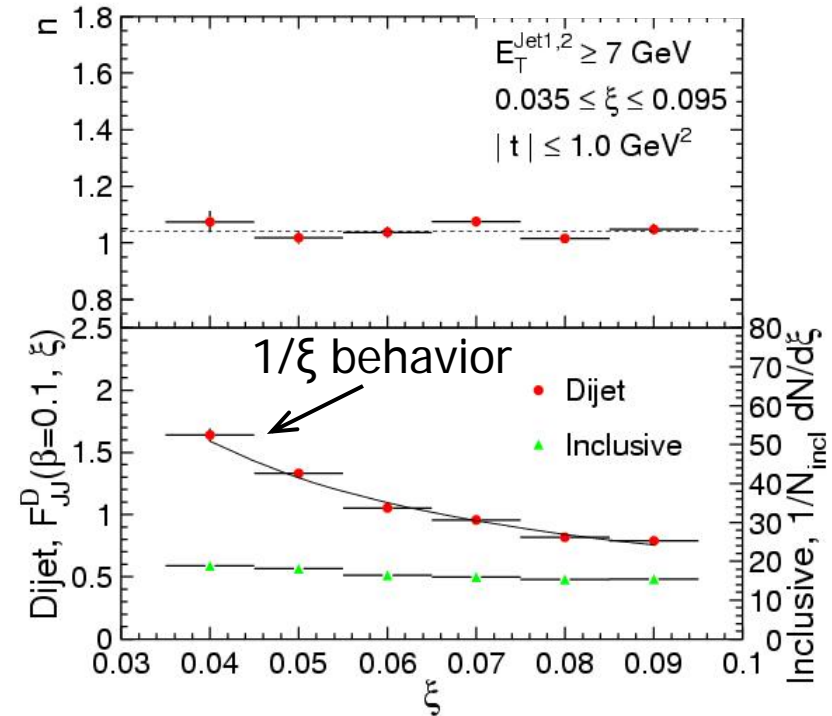
Rate lower by order  $\alpha_s$   
+ 1 associated jet

Run I:  $R_W$  (SD/ND) =  $1.15 \pm 0.51(\text{stat}) \pm 0.20(\text{syst}) \%$

# The Diffractive Structure Function: Run I



discrepancy in normalization  
↓  
QCD factorization breakdown



$$F_{jj}^D = C \beta^{-n} \xi^{-m}$$

Regge factorization holds

for  $\beta < 0.5$   
 $n = 1.0 \pm 0.1$   
 $m = 0.9 \pm 0.1$

Pomeron exchange